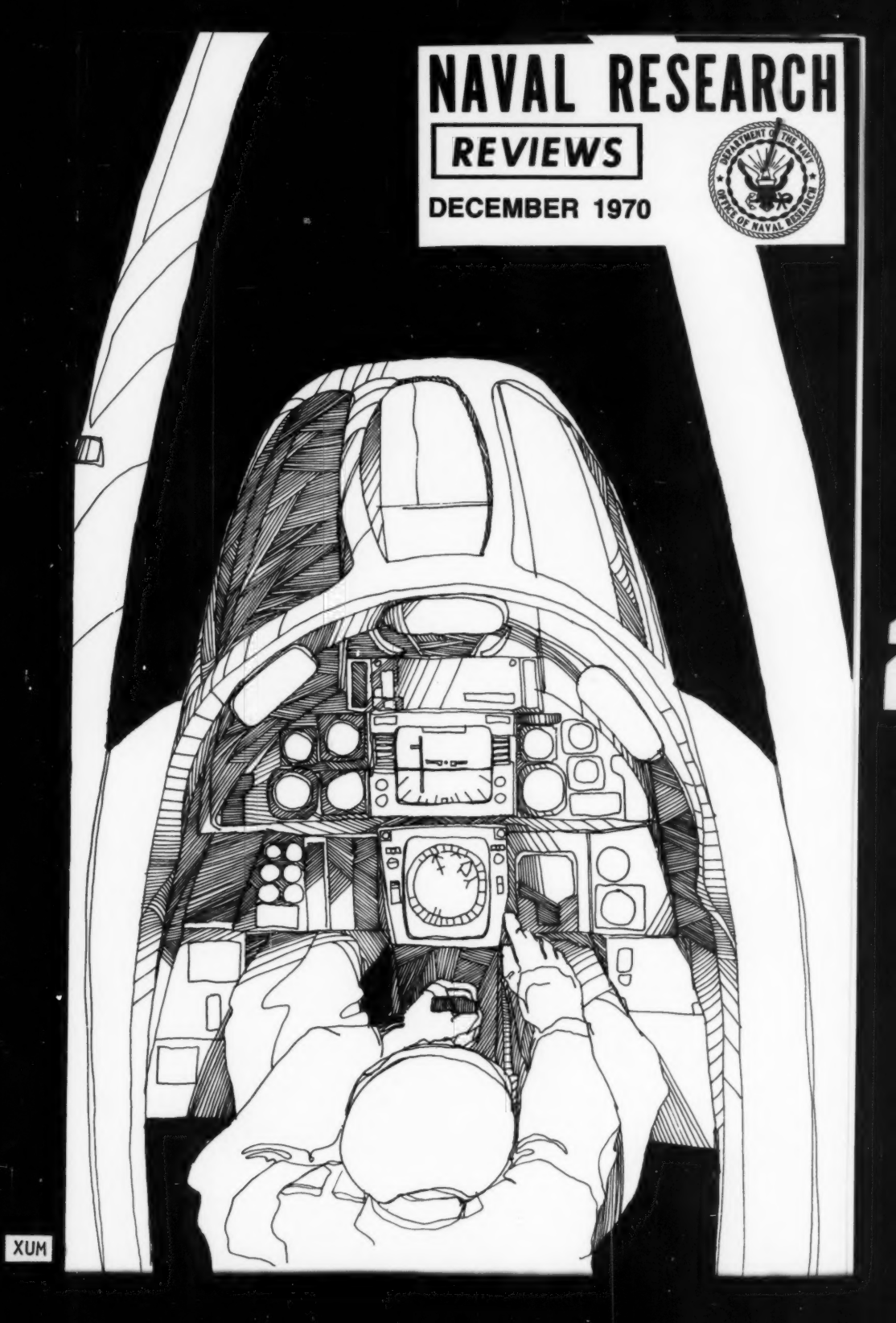
NAVAL RESEARCH

REVIEWS

DECEMBER 1970



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Portraits in Science

Dr. Frederick V. Hunt, a renowned acoustics authority, recently retired from the post of Rumford Professor of Physics at Harvard where he has taught since 1927. During World War II, Professor Hunt organized and directed the Harvard Underwater Sound Laboratory, which operated as a branch of the National Defense Research Council. He developed the acoustic homing torpedo (the first guided missile) and the first scanning sonar. In 1947 Dr. Hunt received a Presidential Medal of Merit for his part in developing the Bearing Deviation Indicator. At the end of World War II, Dr. Hunt entered into one of the first Office of Naval Research contract agreements and has been extremely productive to the present. He has provided outstanding service to the Navy as a member of the National Academy of Science's Committee on Undersea Warfare from its inception in 1946 to the present.

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Aircraft Display Media Research

LCDR H. B. Lyon, Jr.
Office of Naval Research

Introduction

The necessary research to support modern aircraft instrumentation results from the contributions of many diverse fields of endeavor. These primarily include solid state physics, electronics, materials science, human perception, and other psychological factors. The Office of Naval Research incorporates these various disciplines into a contract research program conducted by the Director of Aeronautics (Code 461) under the Naval Applications and Analysis Division (Code 460). The Scientific Officer for Cockpit Instrumentation works for the Director of Aeronautics and monitors both a research (6.1 budget category) and an exploratory development (6.2 budget category) program to provide the necessary R&D base for future applications. Under this program many tasks are being conducted; two of which are represented by the articles following this brief. The purpose of this lead article is to provide a short overview of Display Media research in an attempt to place the following two articles in perspective.

It must be pointed out that this field of research is a complex endeavor. There is no clear cut method developed which uniquely relates an operational requirement to one or even a few physical sciences. There is a "many to one" and "one to many" relationship between the various academic disciplines and the many instrumentation applications. The remainder of this paper will of necessity be a rather arbitrary guide through a few factors which motivated the research into the electroluminescent display material mentioned in the following articles. These two articles represent the contribution of ONR contractors at Sigmatron, Inc. and Schjeldahl, Inc.

Contrast Ratio

The necessary attribute for a display is that a man should be able to recognize the information displayed. Volumes of literature are addressed to this problem. In all this literature one mathematical relationship, Contrast Ratio (CR), appears to be consistent for luminescent displays. Contrast Ratio may be defined as a useful performance measure of an information display. The formula for CR is:

$$CR = \frac{I_{on} - I_{off}}{I_{off}}$$

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where I_{on} = the Brightness of an "on" element in a display and I_{off} = the Brightness of the adjacent background. In the case of a matrix of elements this can be the same element in an "off" status. Let us look deeper into this CR relationship to demonstrate some of the inherent capabilities of thin-film electroluminescent devices.

The human can normally see the difference in brightness between two "on" elements when their intensities differ by a factor of 2. By using the CR formula, this results in a CR value of 1. Displays with this capability are useful for the display of letters and numbers (alphanumerics). For many of the applications of modern aircraft instrumentation a series of differing intensities are required such as for the detail in a TV type picture. The term used to discuss this attribute of a display device is "Shades of Gray." The expression "Five Shades of Gray" means that a set of intensities can be displayed which have ratios of 1:2:4:8:16:32, where the background intensity equals 1.

The values of the intensity of the "on" element and the "off" element can be analyzed in more detail. The "on" intensity is composed of the luminescent intensity (I_{el}) as well as the ambient reflected by the element ($\sigma I_{ambient}$). The reflectivity coefficient (σ) should be defined as:

$$I_{reflected} = \sigma I_{ambient}.$$

For the sake of simplicity, assume the units to be foot lamberts of brightness. The brightness of the "off" element is the reflected intensity. If there is no reflectivity change due to switching an element to the "on" state, then the CR relationship simplifies to:

$$CR = \frac{I_{el}}{\sigma I_{ambient}}.$$

One could argue the approximations in this derivation, especially if we were concerned with quantitative values of the paramenter. The essential point to be recognized is that Contrast Ratio is both a factor of the "on" intensity and the reflectivity of the "off" element. They must be considered together. The implications of an analysis of this type can best be shown by Figure 1, which demonstrates the effect of increasing ambient illumination on shades of gray for a fixed maximum luminescent intensity. The calculation assumes a 100 FL luminescent source and results are shown for various reflectivities. From an analysis of this graph one can see the benefit of a transparent (1 percent reflectivity) element of the type made by Sigmatron.

The value of this low reflectivity can be shown in another way. This is by looking at the increase in luminance required if higher display reflectivities were to exist. The simplest means of increasing contrast is by use of a contrast enhancing filter. Assume that we have a device

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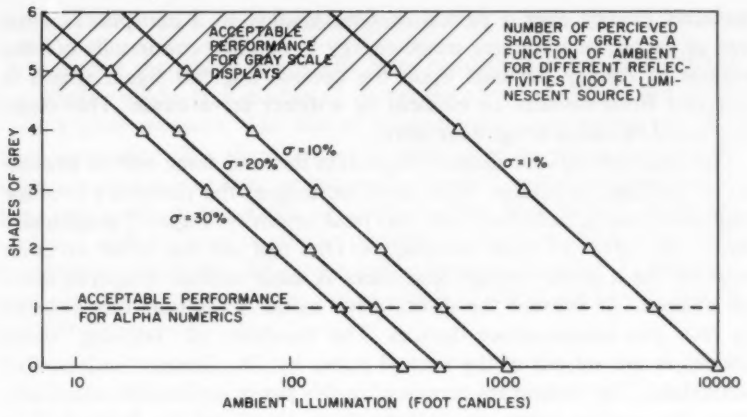

Figure 1

the elements of which have a 25 percent reflectivity, if we use a 40 percent transmission filter the contrast ratio formula would appear as:

$$CR = \frac{.4I_{el}}{(.4)(.4)\sigma I_{ambient}}.$$

For a given ambient the same contrast ratio can be achieved as before but the luminous intensity must be increased by a factor of 2.5. This re-emphasizes the fact that acceptability of a display media will not be determined on brightness alone. The first of the two papers to follow is written by investigators at Sigmatron and it is important to remember the fact that these are low reflectivity display media devices.

Average Brightness

If one discusses display applications for more than a few minutes, the conversation usually resolves to a discussion of display drive mechanisms. This problem is a serious limitation to the application of all display media especially in an x-y matrix addressed mode. The reason for the problem is the requirement to maintain a high average brightness when a large number of elements must be sequentially addressed. There are three classes of element which can be utilized. These can be characterized as a direct drive class, a persistence class and a latched class of display element. The time during which electrical energy can be applied to the illuminating element is the reciprocal of the number of elements in the display. In a direct drive mode Luminescence exists only during the period of excitation. In the persistence class, electrical energy is applied in the same short period of time but is converted to

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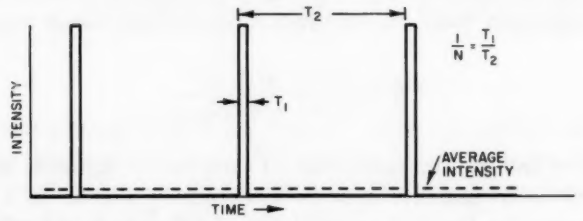
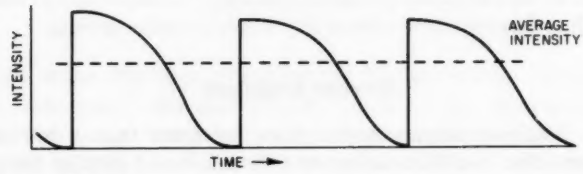
luminous energy over a period of time leading to a phosphorescence type of decay. In a latching mode energy is supplied continually but the amount of energy depends upon the control (logical) signal which is switched from element to element in a direct drive mode. This latter case could be called integral memory.

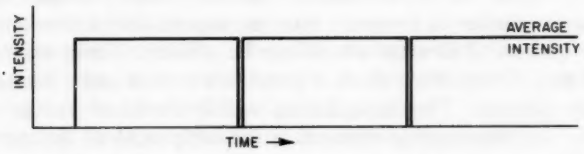
The requirements for display brightness demand some sort of persistent or latching technique. With these techniques the necessary average brightness can be achieved with less peak intensity. Figure 2 graphically shows the effect of these techniques. One can see the effect on peak intensity for a given average brightness as these various modes of drive are utilized. At present the direct drive mode is the only one existing for thin film luminescence devices. The feasibility of "latching" these devices is the subject of the second paper by Dr. Donald Anderson of Schjeldahl. The techniques proposed in this paper are feasible especially when the unique micro-glass technology developed by Schjeldahl is utilized.



A. Direct Drive



B. Persistence



C. Latching

Figure 2 — Intensity as a function of time for 3 classes of display drives

Conclusions

It is hoped that these few words have convinced you that feasibility of a display media is a matter of perceived contrast. Brightness alone is not a good measure. The use of mathematical expressions are valid when we realize that these are only techniques to relate human perception in such a way that we can guide research, select potential candidates and evaluate feasibility of displays. The final test of feasibility is when a military pilot is able to perform his mission effectively under all required conditions. Display media research therefore is aimed at increasing range of conditions under which effective operations can be performed.

Naval Research Laboratory Concerned With Pollution Control

Early in World War II, NRL chemists interested in surface phenomena explored the possibility that films of spreading agents might be used to clear hazardous oil away from sinking ships. However, the novel idea to corral oil escaping from sinking ships failed when it was demonstrated that the spreading films...known as "piston films" could not drive the thick oil accumulations far enough from the ships...and the project was shelved.

In 1968, Mr. William Garrett a research chemist of the Ocean Sciences Division, revived the program in response to the current international concern about oil pollution and began investigating the possible uses of surface acting materials to control oil and chemical scums.

The results of Mr. Garrett's research were demonstrated recently at NRL with the use of drops of the piston film to drive 84 milliliters of Venezuela crude oil across the surface of a 90 square foot pool of water into large clusters at the opposite end.

The "piston film" are composed of surface-active, organic materials, which are nontoxic and insoluble in water. These materials spread rapidly and spontaneously into an extremely thin layer, which is only one molecule thick. As a result, very small quantities of piston film material can clear oil layers from large areas of water surface.

Once the oil has been corralled by the film, it can be removed from the surface by some type of sump pump.

In speaking of the experiment, Mr. Garrett said that large-scale oil spills, like that from the Torrey Canyon, in which the oil thickness is more than a quarter of an inch, could probably not be confined by the films.

However, such large spills are not encountered at Naval Ship facilities where oily pollution arises primarily from fuel tank overfilling and ship leakage. Mr. Garrett went on to say that since small scale-spills thin out rapidly due to spreading, wind, and currents, thick layers of pollutant oil are seldom found. NRL laboratory and field experiments have demonstrated that, under favorable conditions, monomolecular films can be used to guide, confine and condense small-scale petroleum spills.

To prove his point Mr. Garrett headed several other field experiments including one on the Buffalo River, Buffalo, N.Y., which is now almost void of any living matter. A number

(Continued on page 24.)

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Electroluminescence

Edwin J. Soxman, Thomas Fahy, and Gorden N. Steele
Sigmatron, Inc.
Santa Barbara, California

LEF (Light Emitting Thin Film) Displays

The Office of Naval Research, the Naval Air Systems Command, and the Army Electronics Command have conducted a cooperative research program for many years to identify, define, and validate advanced concepts for improvement of the instrumentation systems of future Naval and Army aircraft. The joint effort is designated the Joint Army Navy Aircraft Instrumentation Research (JANAIR) Program, and is directed by ONR. The scope of the program extends to sensing elements, data processors, displays, controls, and man/machine interfaces for fixed and rotary-wing aircraft for all flight regimes.

As one element of this program, JANAIR, through ONR, has supported a materials research program at Sigmatron to investigate and improve the characteristics of light emitting film (LEF) light sources and displays.

This paper gives a broad overview of the characteristics of LEF display elements, including some of the factors involved in their practical application. As a result of ONR's continuing program, these devices have now emerged from the laboratory stage to the point at which practical applications to aircraft instrumentation are entirely feasible.

Cockpit instruments and display surfaces made from LEF's have a number of distinct potential advantages over competing devices such as cathode ray tubes, light emitting diodes, glow-discharge tubes, and the like. The basic light-emitting material may be deposited in large sheets; the desired instrumental readout or other display pattern is then applied in a straightforward electroding process. The display designer therefore has a high degree of flexibility in selecting optimum patterns for readability, and the display is made up of sharply defined, uniformly emitting areas, readable in high or low levels of ambient light over a wide range of viewing angles.

The LEF technique also lends itself to the construction of x-y addressed dot matrices for display of many of the types of information now presented by Cathode Ray Tubes (CRT's); the advantages here lie in the substantially improved ruggedness and compactness that are attainable, and in jitter-free operation, since the location of each display element is fixed rather than subject to vagaries in the positioning of an electron beam.

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General Characteristics

An LEF light source in its simplest form (Figure 1) is a three-layer sandwich consisting of (1) a transparent front electrode, (2) a layer of suitable phosphor, and (3) a back electrode, which need not be transparent, and which is generally metallic. When an appropriate electrical signal is applied between the electrodes, the phosphor in the region between the electrodes emits light. Simple structures of this type have been used for such devices as "night lights," and panel illuminators. If the electrodes are properly configured, legends, symbols, letters, numbers, or other forms of information can also be displayed. *X-y* address dot matrices of display elements are also possible.

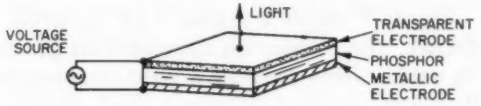

Figure 1 – Simple LEF lamp

Early electroluminescent sources (and some present ones) were made from so-called "settled" or powdered phosphors, in which distinct grains of the powdered material are embedded in a dielectric material. Such sources, although useful, have a number of disadvantages:

- The phosphor layer is opaque, and has a relatively high diffuse reflectivity. Displays are therefore difficult to read in high levels of ambient illumination, because of the loss in contrast between illuminated areas and their backgrounds. Moreover, even with low ambient illumination, halation around the illuminated areas can reduce effective contrast and increase visual clutter.
- The brightness *vs* voltage characteristic is such that each element in a matrix array (discussed below) must be fed through a non-linear series dropping resistor if cross-talk between elements is to be minimized.
- The dielectric layers in which the phosphor grains are embedded tend to have poor environmental resistance, complicating the handling and packaging problems. The effects of humidity are particularly serious.

Distinct improvements are possible in the characteristics of electroluminescent lamps if the powder phosphor layer is replaced by a vacuum-deposited thin film. Because such films are highly transparent, they can be used in conjunction with backing layers of low diffuse reflectivity to improve contrast and to reduce halation (see Figure 2). The electrical characteristics of the LEF lamps are such that multiple series resistors

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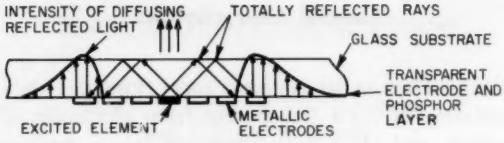

Figure 2 — Halo effect in LEF panel, caused by total internal reflection at the glass/air interface at and beyond the critical angle. This effect can be sharply reduced by use of transparent phosphors and a backing layer with low diffuse reflectivity.

are not required in matrix arrays. If both electrodes are made transparent, the entire light-emitting sandwich will be transparent; so LEF's are also suitable for such applications as rear-projection displays, map overlays, and head-up displays.

Figure 3 shows a typical LEF structure used for a direct-viewing display. The transparent electrodes are generally made from conductive tin oxide, which provides a good combination of mechanical properties (hardness, abrasion resistance, *etc.*), electrical conductivity, and optical transmittance. The phosphor, normally about 2 microns thick, is made from vacuum deposited zinc sulfide (ZnS), doped to an appropriate concentration with manganese sulfide (MnS). The dark dielectric film is a homogeneous, glassy material with appropriate electrical and optical properties. The metallic rear electrodes which define the display

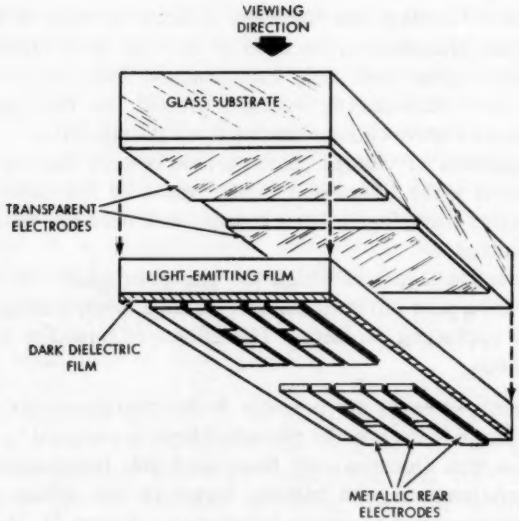

Figure 3 — Typical LEF structure

configuration are usually vacuum deposited using such materials as indium or aluminum.

When an unilluminated display of the type just described is viewed in ambient light, only an intense black, uncluttered surface is seen. When the excitation voltage is applied, the symbols, letters, numbers, or other information appear as crisply defined, uniformly illuminated (predominately orange) areas against this background, free of halation and other disturbing effects. Note that such displays are free of visual clutter over a wide range of viewing angles, a distinct improvement, for example, over conventional glow-discharge types with their three-dimensional arrays of transparent soda straws.

Configurations

The simplest configuration for a LEF display involves a single symbol or legend which is illuminated when an electrical signal is applied across its input terminals. Functional legends, warning lights, *etc.*, fall into this category.

The next level of complexity involves displays that consist of an array of elements which provide information on the basis of what set of elements is illuminated. Examples of such displays are conventional "stroke writing" numerics (or alpha-numerics) and bargraphs. Figure 4 shows a typical seven-segment numeric configuration, and Figure 5 shows a digital clock incorporating such a numeric. Figure 6 shows a typical bargraph, in the form of an engine performance indicator.

A typical segmented numeric requires eight electrical connections—one for a common electrode, and seven for the individual segments. Any arabic numeral can be displayed by lighting the appropriate segments.

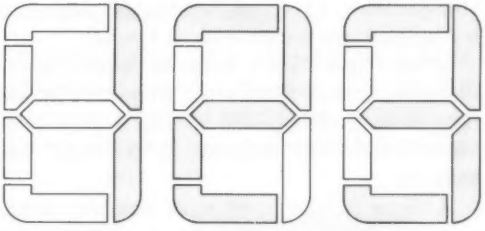

Figure 4 — Typical configuration for a seven-segment numeric, showing the numbers 1, 2, and 3

Figure 5 — Digital clock using LEF seven-segment numerics

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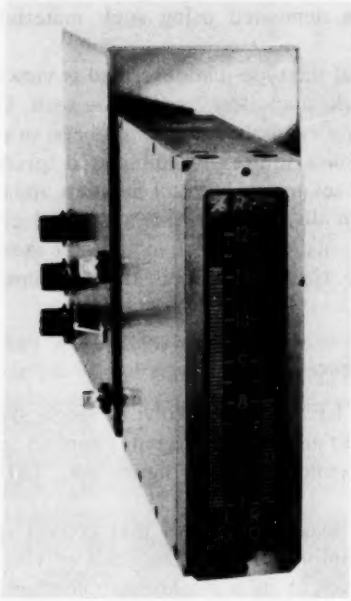

Figure 6 — LEF bargraph display demonstrator

Displays of this type are usually operated with each element energized continuously when it is on, and de-energized when it is off. For direct drive at a display of five digits, an absolute minimum of 36 electrical connections is required: 7 for the segments on each digit, and 1 for a common. In practice, each digit will have a separate common connection, bringing the total to 40. In all, 35 electrical switches are required in this configuration. One can see that if more than 5 digits are desired the wiring problem grows without bounds.

If the segments are scanned sequentially at a rate above the critical fusion frequency (CFF) (the frequency at which perceived flicker of the light source disappears) a satisfactory five-digit display can be provided which only requires 12 electrical connections and 12 electrical switches.

A more familiar (and more flexible) display is the rectangular cross grid, which is the solid state analog to a television picture tube. In a typical array of this type, the transparent conductors are etched to form a row set of equal-width parallel bars with equal (but much narrower) spacings (Figure 7). The metallic electrodes form a similar column set. If the switches controlling the electrical input to a selected row and a selected column are closed, the rectangular element at their intersection will be illuminated. Scanning operation is possible, so the duty

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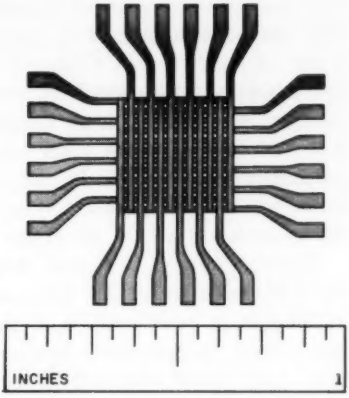

Figure 7 – Crossed electrode configuration of small LEF test panel

cycle need never be greater than $1/n$, where n is the number of rows or columns (or the smaller of the two, if they differ).

Arrays of seven rows by five columns provide a sufficient number of elements for display of any selected letter or digit. Arrays with a moderate number of rows and columns are therefore capable of displaying alphanumeric words of reasonable length. (See Figure 8, where the word "NAVY" is displayed on a small 28 × 28 cross grid. Arbitrary patterns and symbols can also be displayed in this way. Flexible, all-solid-state readouts characterized by excellent readability, compactness, ruggedness, and low power consumption are therefore possible by application of this technique. Transparent versions can also be used in such applications as map overlays, and for superimposing data on rear-projection displays.

Short-Term Brightness Variations

The brightness *vs* voltage characteristic of a typical LEF is highly nonlinear, and may be approximated over a certain range by $B = B_o \exp\ [-(V_o/V)^{1/2}]$, where B is the observed brightness, V is the applied voltage, and B_o and V_o are empirical parameters dependent upon

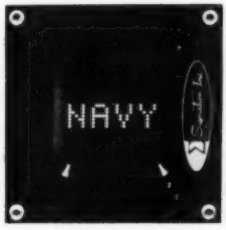

Figure 8 – Word display on small cross grid

temperature, frequency of the applied voltage, phosphor characteristics, and construction details of the LEF cell. According to this equation, a plot of log B *vs* $1/\sqrt{V}$ should yield a straight line, a condition closely approximated in hundreds of measurements on LEF's. For 5 KHz excitation, values of B_o have ranged from 10^9 to 10^{62} ft-L, and of V_o from 4×10^4 to 350×10^4 volts rms. Obviously, B_o and V_o are graphical parameters to which little physical significance can be attached at this time. Nevertheless, these physical constants are useful in characterizing the behavior of a LEF phosphor over a limited range.

Figure 9 shows a typical brightness *vs* voltage curve for an LEF for c-w operation at 2.5 KHz, and Figure 10 shows typical brightness *vs* frequency relationships at fixed voltages. Although the curves do not extend to extremely low levels, note that at voltages one-half or less than those required to attain reasonable operating levels (*e.g.*, 10 foot lamberts), the brightness will be very low. This factor is highly favorable in suppressing cross-talk in cross-grid arrays, as mentioned previously. A curve for a typical powder phosphor lamp, plotted on the same scale, would have a substantially lower slope.

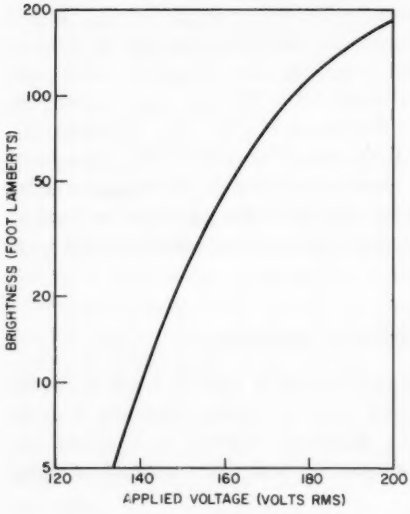

Figure 9 — Typical brightness and voltage characteristic for LEF driven at constant frequency (2.5 KHz). High contrast numeric element, 0.40 inch high.

Cyclical operation of LEF's at rates above the critical fusion frequency are also of interest. Typically, for this type of operation symmetrical sinusoidal excitation is switched "on" for an integral number of cycles at a zero crossing, and held on for an integral number of cycles. It is then turned off until the next application of an identical train of excitation cycles, with the process continuing at a fixed repetition rate. The duty cycle, or fraction of the time that excitation occurs, is equal to the "on" time, divided by the repetition period.

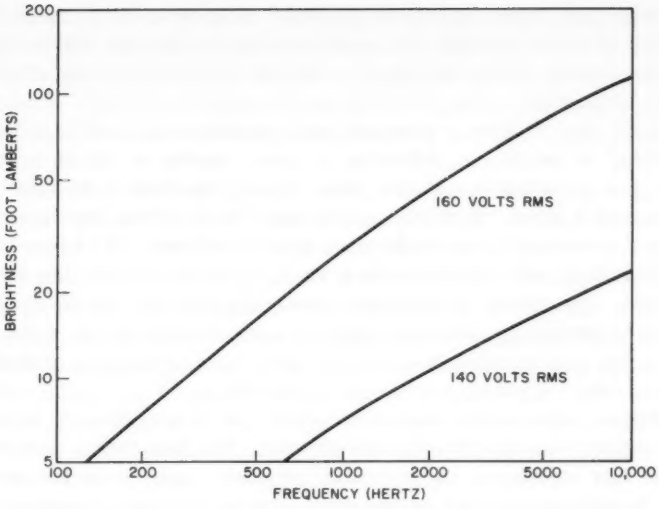

Figure 10 — Typical brightness and frequency characteristic for LEF driven at constant voltage. High contrast numeric element, 0.40 inch high

As a first approximation to estimating the effects of duty-cycle operation, one could assume that if the duty cycle is $1/K$ then the peak brightness would have to be K times greater than the value desired for presentation. The corresponding voltage to be applied during a pulse would then be chosen from a curve such as that of Figure 9 for the appropriate operating frequency.

Actual duty-cycle operation of an LEF deviates from this simple model for a number of reasons associated with both the electrical and performance characteristics of the device. The simple equivalent circuit is a form of low-pass filter, so that the voltage actually applied across the light-emitting element differs from the voltage applied at the input terminals. A significant rise time can therefore be associated with the application of pulses of excitation, causing an associated delay in the onset of luminance. This factor is more severe for large capacitances, and for large series resistances.

Brightness Variation

When an LEF lamp is excited at constant voltage, its brightness will vary somewhat with time. These variations fall into two general categories: initial turn-on effects, and longer-term brightness maintenance. When an LEF lamp is turned on for the first time, there is an initial delay in attaining steady-state brightness that is much longer than the

delay discussed above for pulsed operation. This delay is commonly on the order of a few seconds; delays at subsequent turn-ons will be substantially shorter, unless the lamp is idle for very long periods of time (months or years).

An LEF driven from a constant-voltage source will exhibit a long-term decay in brightness, following a curve roughly of the form $B = B_o / (1 + t_{1/2})$, where $t_{1/2}$ is the "time to half brightness." At a driving frequency of 5 KHz, values of $t_{1/2}$ of several hundred to a few thousand hours are commonly attained from an initial brightness of 10 foot lamberts. Times to half brightness tend to decrease with increasing initial brightness. The effects of operating frequency and duty cycle are not yet well established, although there are some indications that slower decay rates are associated with low duty-cycle operation, and that operating frequency does not have a strong effect.

Brightness maintenance values, however, are only indirectly related to the ultimate useful life of LEF displays. The fact that a lamp has reached half brightness, or any other arbitrary value, does not mean that it is approaching end of life. Only a minor voltage adjustment is needed to restore the lamp to its initial brightness, and its subsequent rate of brightness decay will be lower than its previous value.

After many such resettings, the operating voltage will approach the voltage at which the LEF structure will break down electrically. For this reason, additional protective dielectric layers, not shown in Figure 3, are included in practical structures to increase the ratio between operating and breakdown voltages. A common figure of merit is the ratio between the voltage required for breakdown and the voltage for 10 foot lamberts for operation at 5 KHz. This ratio is approximately 1.5 for structures without protective layers, but may be as high as 3.0 or more when such layers are included. Note that a factor of two in overvoltage capability represents several orders of magnitude in reserve brightness, because of the steepness of the brightness *vs* voltage characteristic.

If an LEF lamp is driven in a constant-current rather than a constant-voltage mode, brightness will remain sensibly constant for long periods without electrical adjustment.

Electrical Drive Considerations

The two basic elements required for driving typical LEF displays are a source of electrical excitation, and switches for controlling the application of excitation to selected elements.

The driver must be capable of supplying the required operating voltage to the LEF, usually over moderately large variations in load as affected by the maximum and minimum number of elements to be switched on at given times. Symmetrical waveforms with zero average voltage are preferred; d-c offsets tend to reduce the luminous efficiency and increase

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the rate of degradation of the lamps. Very rapid rise times, such as those associated with square waves, are unfavorable because of the large charging currents that result when a capacitive load is driven from such a source. The peak voltage should be restricted to values safely below the voltage for a-c electrical breakdown of the LEF, under all driving conditions.

These restrictions generally result in selection of a sinusoidal or quasi-sinusoidal driving waveform, although trapezoidal and other harmonic-rich waveforms have been used successfully.

Switches for controlling the application of excitation to the LEF elements must be capable of withstanding the applied voltages and passing the required current, should have appropriate "on" and "off" resistance values, and should exhibit a speed of response appropriate to the application. In general, speed should be sufficient to permit switching at or near zero-crossings; otherwise, large voltage transients may be applied across the LEF, with undesirable effects as described for square-wave operation.

In general, solid-state switching elements have been used for LEF drive. Mechanical elements, such as reed relays, have also been used; however, special precautions must be taken to avoid disturbances introduced by contact bounce, and to achieve operation approaching the electrical equivalent of zero-crossing switching.

Solid-state switches can be considered as two-state variable resistors which present a moderatlely low resistance when turned "on," and a moderately high resistance when turned "off" in response to a low-voltage two-state control signal. The "on" or saturated value of resistance will normally show a moderate variation among units, even in well-designed switches. Care must be taken in the design to insure that the variations in voltage drops across the switches do not cause noticeable variations in brightness among the associated driven elements. The values of "off" resistance will also vary somewhat, but this is generally a less important factor. Low values of control or gating voltage are desirable for compatibility with normal logic levels. Power requirements are usually an important factor, even when total power consumption is not critical, since heat dissipation may restrict the extent to which miniaturization is possible.

Single-Element Display Drivers

Simple LEF configurations such as warning lights, legends, and the like may be driven continuously, requiring a switch to turn them "on" or "off" only for long periods of time. For such applications, LEF's may be designed to be driven directly from the power line at common aircraft frequencies such as 400 or 800 Hz, or with modest voltage

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step-up, from conventional 60 Hz power. Simple oscillator/amplifier configurations are also entirely feasible, as are free-running multivibrators, if care is taken to ensure that the waveform actually applied to the LEF does not have inappropriately short rise and fall times.

Switches for LEF Arrays

LEF technology readily lends itself to the fabrication of linear and two-dimensional arrays with a high density of light-emitting elements. Linear arrays, such as bargraphs, are entirely feasible with 100 or more elements per inch, and cross-grid arrays with 1000 or more elements per square inch are within the state of the art. Compact, reliable, and highly efficient switching devices are therefore required if the full potential of LEF devices is to be reached.

Many array-type displays, of course, do not require such large numbers of elements, and are entirely suitable for use in conjunction with discrete-component electronic switching circuits. Integrated circuit technology is rapidly advancing to the state at which it will be fully compatible with LEF requirements, and LEF's themselves are also being developed to have more modest voltage and power requirements. Full integration of LEF's and IC's can therefore be expected with confidence in the near future.

Summary

Light Emitting Film (LEF) displays have distinct promise for increasing the legibility, reliability, and compactness of aircraft instruments. As the result of JANAIR/ONR sponsored materials research, LEF technology has been brought from the laboratory stage to the point at which a broad range of applications are entirely feasible. Compact packages incorporating modern integrated circuits are a near-term possibility, as replacements for CRT displays, dial and bargraph indicators, numeric readouts, and the like. The pattern flexibility inherent in LEF technology allows known human factors principles to be brought into full play. Widespread applications to improved instruments for future aircraft can therefore be expected with confidence.

4th Symposium on Engineering Problems of Fusion Research

The symposium will be held at the Naval Research Laboratory, Washington, D.C. on April 20-23, 1971. The primary purpose of the symposium is to continue the much-needed informal exchange of information on fusion technology among engineers actively engaged in high energy plasma problems. Address all correspondence to M. P. Young, Code 7708, Naval Research Laboratory, Washington, D.C. 20390.

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The Possibilities of a Solid State Display Panel with Integrated Storage

D. E. Anderson and R. L. Swisher
G. T. Schjeldahl Company
Northfield, Minnesota

One of the more attractive approaches to providing a multi-format display with a large number of resolution elements (10,000 or more) has been the matrix addressed electroluminescent panel. In such panels, excitation voltages are applied between a desired column-select address line (x-select) and a desired row-select address line (y-select). On the face of the panel, the cell at the intersection of (x,y) should then glow.

The major attraction of the electroluminescent display approach has been the possibility of batch fabrication of a very large number of display cells. The individual cells can be made as small as required compatible with adequate character recognition at normal display viewing distances (the limiting resolution at 20 inches is ~0.009 inch); total panel areas of several feet on a side have been proposed.

This paper will describe an approach in which a storage panel is used to present a fixed, 100 percent duty cycle display which can be matrix addressed.

The simple matrix-addressed electroluminescent panel requires an electroluminescent material with a steeply super linear dependence of brightness on voltage, capable of being driven to very high instantaneous brightnesses. This must be coupled with electronics capable of applying high voltages of desired amplitude and phase to all columns and rows at a high scan rate, refreshing the entire display with a repetition rate above the flicker frequency. Finally, the electronics must be backed up by a page-oriented memory, into which display update occurs and from which the row and column drivers must read at high rate the switching inputs to the display panel.

The concept of providing display storage within the display panel itself is suggested by all of the above requirements.

Matrix-Addressable Display With Storage

In its most general form, what is desired is an input switch in series with each electroluminescent cell in the entire panel. The switch itself should have two matrix-oriented inputs, so that the simultaneous application of x- and y- pulses to the switch latches the switch in an "on"

state. The application of either pulse alone should not latch the switch. The switch when latched would apply an AC voltage continuously to the electroluminescent display cell, until some erase signal is applied, either selectively or to all switches.

Before proceeding to any discussion of the nature of the proposed "switch," let us point to the advantages resulting for the entire display system.

First, *brightness:* The electroluminescent cell will be maintained at full available brightness, without duty cycle limitations, during the entire display period between erasures. Since average brightness equals peak brightness (Figure 1), independent of panel cell capacity, this is particularly necessary for large panels.

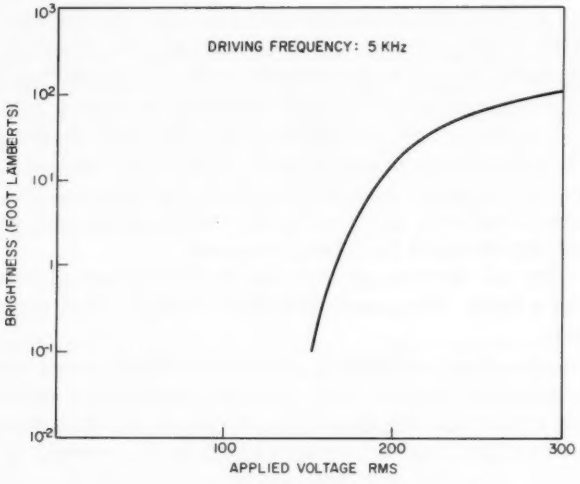

Figure 1

Contrast: If the switch truly blocks the voltage path to the electroluminescent material, panel contrast (both average and line) can approach infinity. Contrast ratio to ambient light remains finite; however, since the same contrast enhancement techniques of antireflective coatings are available as with duty-cycle-limited displays, this contrast ratio will also improve with unity duty cycle.

Electronics: Since we have yet to define the "switch," it is not clear that peripheral drive requirements are relaxed. However, note that the requirements for periodic refresh at a flicker-free frequency, line-at-a-time switching, and high peak voltage are all related for integrated latching panel.

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Memory: The requirement for a page-oriented buffer memory to service the panel refresh function is, for many purposes, removed. The latched display serves as its own memory; moving that memory from "behind" the electronics to "in front of" the electronics is entirely adequate for many display-only applications, and makes the "memory" itself visually observable.

Now, let us examine the nature of our proposed "switch" itself. This "switch" could be in principle of conventional electronic circuitry (*e.g.*, triacs or SCR's), of saturable reactance type, or even of relay configuration. However, note that the number of switches required is $N_x N_y$ and not $(N_x + N_y)$ as for matrix drive lines. Hence, for N_x and N_y both large, a very low unit cost, labor-free interconnection techniques, and small packaged size (comparable to cell size) are mandatory.

The one switching function that seems truly attractive is based on optoelectronic coupling, using again an electroluminescent layer as an input and a photoconductor as the output. This "EL-PC Relay" is quite analogous to many other optoelectronic relays, as for example a light-emitting-diode optically coupled to a photoconductor, in providing good input-output isolation of the "relay," and the high voltage AC switching capability of the photoconductor.

In order to arrive at an integrated, matrix-inputted "switch," the input EL device is a matrix addressable EL panel of the type previously described. Momentary application of voltage pulses ($+V$ and $-V$ to selected x and y inputs) will produce a momentary pulse of light which is optically coupled to one photoconductor which is, in the dark, of sufficiently high impedance to clock an applied voltage from the output EL lamp.

We must still provide a mechanism for "latching" our PC switch into a low impedance "on" state which will persist even when the input pulse is removed. Our mechanism must also be sufficiently selective so that an input light pulse of lower intensity (b_2 or b_3 for $V/2$ or $V/3$ input matrix excitation) will *not* cause "latching" into the "on" state.

The technique used to accomplish this selective latching technique can be described as optical feedback, with a carefully calculated amount of the output EL light fed back to the photoconductor. The overall system is thus an EL-PC-EL switch, in which a *momentary* voltage pulse applied to the input (the electrodes of the first EL layer) results in a *continuous* light output from the second EL layer.

The system being considered is shown schematically in Figure 2. The EL element at the bottom of the figure (one of many elements in an *X-Y* array) is briefly pulsed. This lowers the resistance of the PC element. If the top EL element in combination with the PC has a luminous gain function of the proper nonlinear shape, the top EL element "locks" or "latches" itself on.

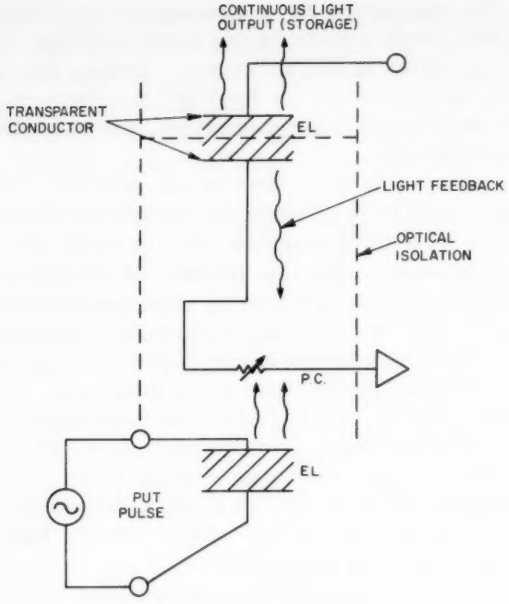

Figure 2 — Electro-optic circuit for EL storage panel

Figure 3 shows two different ways to visualize how "lock-up" or "optical latching" occurs. The graphs are plots of output EL brightness (B_o) versus external input EL brightness (B_i) for a single display element. The symbol β represents the fraction of output light allowed to internally stimulate the PC. The curves corresponding to $\beta = 0$ represent the output EL-PC operating with no internal optical feedback and hence as only a light amplifier. The lines labeled β_1, β_2, and β_3 in Figure 3a represent the additional B_i generated from B_o if the feedback fraction is β_n, so that the total input is $B_i + \beta B_o$. Figure 3b shows the input-output curves for the light amplifier with internal feedback factors of β_1, β_2, and β_3. The values of B_i used in the plot represent external input light only. For example, the curve in Figure 3b labeled β_1 was obtained from the simple light amplifier curve ($\beta = 0$) in Figure 3a, by subtraction of the B_i values of the β_1 curve from the B_i values of the $\beta = 0$ curve.

It is seen in Figure 3b that the curve β_2 represents the critical lockup curve for the device. If the external light input B_i advances from 0 to B_{i2}, the device bootstraps itself along the vertical dotted line to the upper curve very rapidly and if B_i increases further, the output B_o moves along the upper portion of the curve. If B_i is decreased to zero, B_o moves back along the upper solid curve to B_{o2} where it remains latched be-

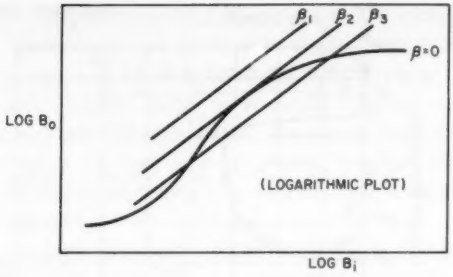

Figure 3a

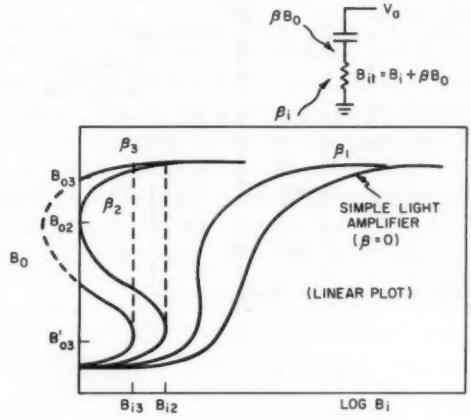

Figure 3b

cause of internal optical feedback. B_{o2} is the minimum output light in the lock-up state. B_{i2} is the maximum necessary input light to latch the device. A more useful feedback fraction β_3 is illustrated by the curve labeled β_3. When the input light B_i has advanced to B_{i3}, the output light jumps rapidly to the upper curve and follows that curve for increasing B_i. If B_i then diminishes to zero, the output light moves back along the upper curve to the value B_{o3} which is the value maintained by internal feedback ($B_i = \beta_3 B_{o3}$). With a feedback fraction of β_3, the output brightnesses between B'_{o3} and B_{o3} are not stable states. It should be remembered that the external B_i is provided by a pulse of light at the intersection of a crossed grid matrix. It is noted that in Figure 3b the curve labeled β_1 represents a light amplifier cell with sub-critical feedback. This configuration will not lock up but can provide very large values of gain (B_o/B_i) over limited ranges of B_i.

The overall operation of the EL-PC-EL combination can now be considered with the aid of Figure 4. In this figure the input EL characteristic is shown in the lower portion (input voltage *via* matrix lines *vs* its output brightness); this is as shown earlier in Figure 1. The upper portion

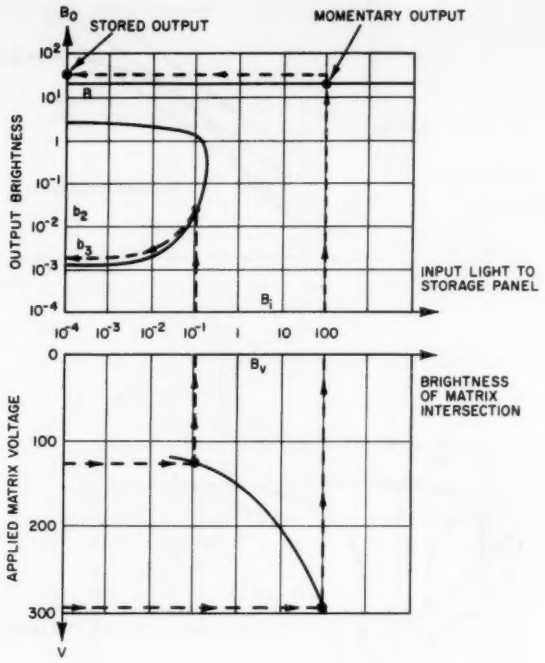

Figure 4

of the figure is the input/output characteristic of the PC-EL latching section with appropriate feedback; this is as shown earlier in Figure 3a.

The full applied voltage (+150 v on an *x*-line, −150 v on a *y*-line) produces a pulse of light from the input EL of 200 foot-lamberts. This input will tend to drive the output section to B_1 on Figure 3a. When the input is removed, the output latches at $B_{o3} = 20$ foot lamberts.

Non-selected cells will, during the pulse, go to a brightness of less than 0.1 foot lamberts (for both biasing schemes, either $V/2$ or $V/3$ applied). Thus, *during* the pulse, the contrast ratio is either $C_p = (25)/(.02) = (125)$ ($V/2$ applied) or $C_p = (25)/(.001) = (25{,}000)$ ($V/3$ applied).

After the pulse (in the latched state), the ratio in the stored state is $C_s = (20)/(.001) = 20{,}000$.

One Configuration of an Integrated Storage Panel

Approximately one year ago, the G. T. Schjeldahl Co. began the development of a flat Matrix Addressable Planar Panel with Storage, MAPPS™. Foremost among the design objectives was the requirement that the panel be easily manufactured. Careful evaluation indicated that

a basic display element dimension of 0.020 inch × 0.020 inch (roughly double the resolution limit of the eye at 20 inches) and output brightness of ~10 foot-lamberts (green), in conjunction with present contrast enhancement techniques, would yield a versatile display panel. To achieve the goal of a low cost display panel, the number of active elements per display bit must be kept to a minimum. Another reason for reducing the number of active elements is to increase the manufacturing yield per layer of the device.

Figure 5 shows the element geometry of the MAPPS latching PC-EL section. This section is built much like a conventional mosaic PC-EL light amplifier. Several modifications are made in order to provide the optical feedback from output EL to input PC, and in order to provide opaque barriers to external illumination and for cell-to-cell isolation (see Figure 4). The vertical dimension is exaggerated. This type of construction allows one to use a thin film photoconductor and to use it in such a way as to minimize capacitive shunting of the PC material.

Figure 6 shows schematically the total MAPPS display panel. The storage light amplifier panel is driven by a sinusoidal A.C. power supply. Typical voltages are in the range of 80 *V* rms to 150 *V* rms. Typical frequencies are in the range of 1 KHz to 8 KHz.

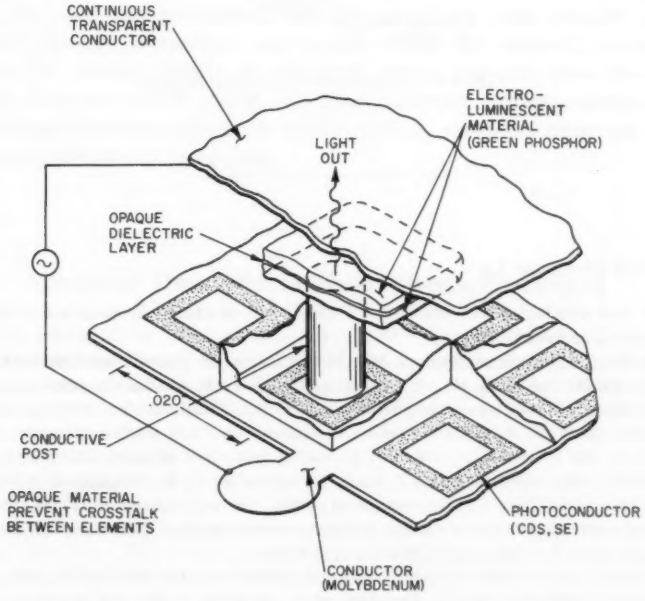

Figure 5 — Simple 3D geometry of PC-EL storage display section

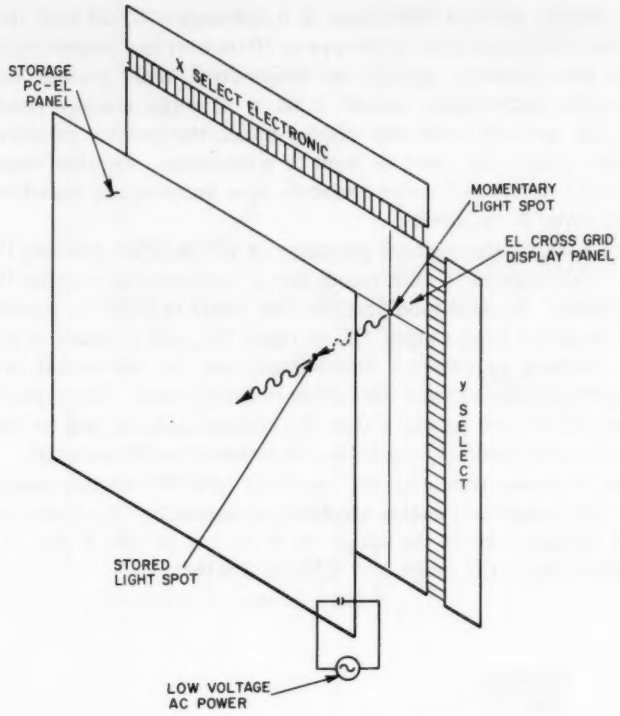

Figure 6 — Functional EL storage display

(Continued from page 5.)

of tests were conducted with both freshly spilled and weathered hydrocarbon pollutants, which were successful.

As a result of these investigations Mr. Garrett said many practical applications for this method were demonstrated. He related that in the open water, oil slicks may be compressed to small thickened lenses by a peripheral control film and maintained in that condition for subsequent retrieval. A spill may be driven from shore when winds and water surface flow are parallel to, or offshore, thereby protecting waterfront property until the pollution has moved on to a less vulnerable location; oil can be driven from inaccessible locations under piers and between ships into open water where recovery operations are possible and; petroleum slicks and chemical surface pollutants can be cleared from water surface with small quantities of the one-molecule-thick piston films.

Mr. Garrett said that he is presently awaiting a report from the Norfolk Naval Facilities Engineering Command, Atlantic Division, as to the value of his new discovery to the Navy's war on pollutants.

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On the Naval Research Reserve

Reserve Assistants Meet in ONR Washington

RADM C. O. Holmquist, USN, Chief of Naval Research opened the annual Conference of Reserve Assistants for the Research Reserve Program at the Office of Naval Research, Arlington, Virginia.

It was emphasized throughout the conference that the need for the Research Reserve Program is as great as ever but that changes are necessary to reflect the revised mission and to increase the benefits available to the Navy through increased use of reservists in contributory roles.

The "Research Reviews," as well as the Research Reserve Information Letter, will be used to keep the Research Reserve Units up-to-date on the latest status of the program.

NRRC 11-5 Field Trip

NRRC 11-5, San Diego, California made a field trip to the Tactical Advanced Combat Direction and Electronic Warfare (TACDEW) Simulation System. TACDEW is a computer based system used for Navy command and control training. Realistic environments, complete with wind and sea conditions, sensors, weapons, and vehicles with authentic motion parameters, are created within the system's computer complex for a wide variety of individual, team, and task force training in such areas as AAW, ASW, electronic warfare, surface operations, air intercept control, carrier air traffic control, weapons direction systems, and amphibious operations.

Advanced Data Management System Developed

The first release of the advanced data management system developed by the project on Computer Aids to Human Intellect sponsored by the Information Systems Program of ONR has been placed into regular service on the RCA Spectra 70/46G time-shared computer system at the Moore School of Electrical Engineering of the University of Pennsylvania. The system provides extensive facilities for information storage and retrieval, multi-level access control, and general problem solving.

Incorporating a number of new concepts in the areas of file structure, data protection, and time-shared operating systems for large-scale computers, the new data management system represents a major portion of the work carried out over the past several years under the direction of Drs. Noah S. Prywes and David K. Hsiao, principal investigators of the project. The system allows file owners to specify various types of access not only

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to their files, but to records of information within those files as well. The generalized file structure incorporated in the system, and its associated storage and retrieval algorithms, permit the user to choose among a number of possible file structures, including the well-known inverted, multilist and index-sequential files. Such a choice of file structures in a single system has never before been available. The system also provides for the definition of problem solving procedures and allows users' programs to request data management service during execution.

Several other projects at the University are already proceeding with plans to utilize the advanced system. Among these are: a Naval War Game project emphasizing the management of strategic and tactical information, a Medical Information Retrieval and On-line Diagnostic project involving interspersed computation and data retrieval, and a Computer-Communication Based Education system which requires controlled sharing of common files of engineering concepts material.

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A Computer Program for Solving Convex Programs

The computer solution of linear programming problems, provided they are not excessively large, is strictly routine business; unless some additional structures exists, solving the general nonlinear programming problem is hopeless. A structural concept which has proved to be particularly powerful for attacking nonlinear programming is the notion of convexity. If a problem is convex it is possible to move from any admissible point to any other admissible point along a straight line lying completely in the admissible set, a technicality of great usefulness. Even more important, it is possible to approximate convex programs with linear programs. There are now several reasonably good algorithms for solving convex programming problems. Although these algorithms are not as relatively efficient as those for linear programming, it is possible to solve real, applied convex (nonlinear) programming problems at a reasonable cost. Fortunately for those wishing to solve them, some of the important programming problems from logistics and resource allocation, if not linear, are convex or "almost" convex. There are, of course, very important problems which are hopelessly nonlinear and nonconvex, but the class of convex problems is large enough and significant enough to merit special attention.

The recent report "CONVEX: A Computer for Solving Convex Programs," by H. O. Hartley, R. R. Hocking, L. R. LaMotte, and H. H. Oxspring presents a description and documentation for one of the more successful algorithms. This algorithm is not new. The basic idea was published by Hartley and Hocking in 1963. The present report is important because it contains program documentation, thus making the program more widely understood and available to potential Navy users. Professor Hartley and the members of his research group have used CONVEX and its extensions on applied military problems including a warhead design problem for the Harry Diamond Laboratories.

Extreme Pressure Sulfide Lubricants

M. J. Devine, Naval Air Development Center and J. R. Soulen, Pennwalt Corp. visited ONR to report on current developments and new concepts in extreme pressure lubrication. Certain arsenic and antimony sulfides originally synthesized by Pennwalt as early examples of inorganic polymers have, during the last three years, been investigated as lubricants at Navy's Aero Materials Department, NADC, Philadelphia in collaboration with the Pennwalt group.

Complex sulfide compositions such as $AsSbS_4$ show extremely high load carrying capacity, antiwear properties and compatibility with a variety of metals and alloys both in composite solid films and as EP additives in grease formulations.

NADC has recently initiated work for NAVAIR on a high-load carrying swing-wing pivot capable of sustaining bearing stresses of 100,000 psi as compared to a 20-30,000 psi limit in present teflon-lined pivot designs. The new design concept incorporates both the use of complex metal sulfides and electrostatic deposition for producing the composite high performance bearing surface. Devine estimates that the use of mixed sulfides as extreme pressure lubricants will reduce the weight of the pivot from 20 percent of the total wing weight (present designs) to 9 percent. Devine's group is also writing a new military specification for greases incorporating complex sulfide additives with far greater EP properties than are now available with commercial additives such as MoS_2. The greases are intended for application on heavily loaded, slowly moving parts, *e.g.*, aircraft landing gear.

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Learner-Controlled Computer-Assisted Instruction

Berkeley Enterprises, Inc., under ONR Contract is conducting research in Learner-Controlled Computer-Assisted Instruction, *i.e.*, computer-assisted instruction *controlled* by the user, rather than by the computer. The purpose of the research is to design several "small" and "interesting" computer programs which: (1) are attractive, even stimulating, to the user, (2) are controlled by the user, in the sense that no specific paths through the knowledge to be learned are prescribed by a teacher; and (3) produce understanding of the subject to be learned. In this context, a computer program is small if it requires on the order of 500 to 800 instructions in machine language; and a computer program is interesting to a user if the user shows by his behavior that the interaction is emotionally exciting and intellectually stimulating. Thus the program leads him to experiment with the computer and find out much of what is to be learned through the experimentation.

One of the unique assumptions in this task is that it is assumed that the computer program is auxiliary to a textbook or manual, which contains information, instruction, and guidance for the user. In other words, the computer program helps in producing an understanding of a topic, but does not stand by itself, nor does the program replace a conventional text.

This task plans to design two to four small interesting computer programs which will accompany topics that are, or could be, in Naval manuals and which will aid in the learning and understanding of these topics. For an initial effort, an existing program which was available at Berkeley Enterprises, Explainer of Probability and Statistics, is being modified. This program has a number of limitations, but it is interactive and it is providing a vehicle to test some of the hypothesis without having to start from scratch. The next topic to be attempted will be based on the subject matter of Chapter 2 of the Navy BuPers Manual for Damage Controlman 3 and 2. This will provide significant, Navy-related subject matter.

NAVAL RESEARCH REVIEWS publishes highlights of research conducted by Navy laboratories and contractors and describes important naval experimental facilities. Manuscripts submitted for publication, correspondence concerning prospective articles, and changes of address, should be directed to Code 109, Office of Naval Research, Arlington, Va. 22217. Requests for subscriptions should be directed to the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C., 20402. Subscription price: $1.75 per year in the U.S. and Canada; $2.25 per year, foreign; $0.20 per individual copy. The issuance of this periodical approved in accordance with Dept. of the Navy publications and printing regulations.

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Through the use of Light Emitting Film (LEF) displays, there will be increased legibility, reliability, and compactness of aircraft instruments.

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R. L. SWISHER

This paper describes an approach to a display panel in which a storage panel is used to present a fixed, 100 percent duty cycle display which can be matrix addressed.

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Stylized drawing of the Navy-Grumman F-14 cockpit featuring a new multimode display developed by IBM. Reprinted by permission of IBM.

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